



NOTIONAL RADIATION HARDNESS (RHA) PLANNING FOR NASA MISSIONS: UPDATED GUIDANCE

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Acronyms

CDR	Critical Design Review (CDR)
COTS	Commercial Off The Shelf (COTS)
EEE	Electrical, Electronic, and Electromechanical (EEE)
GCRs	Galactic Cosmic Rays (GCRs)
JPL	Jet Propulsion Laboratories (JPL)
NEPP	NASA Electronic Parts and Packaging (NEPP)
NOVICE	Numerical Optimizations, Visualizations, and Integrations on CAD/CSG Edifices (NOVICE)
NSREC	Nuclear and Space Radiation Effects Conference (NSREC)
RHA	Radiation Hardness Assurance (RHA)
SAA	South Atlantic Anomaly
SEE	Single Event Effect (SEE)
SEECA	Single Event Effects Criticality Analysis (SEECA)
SEEs	Single Event Effects (SEEs)
SMEs	Subject Matter Experts (SMEs)



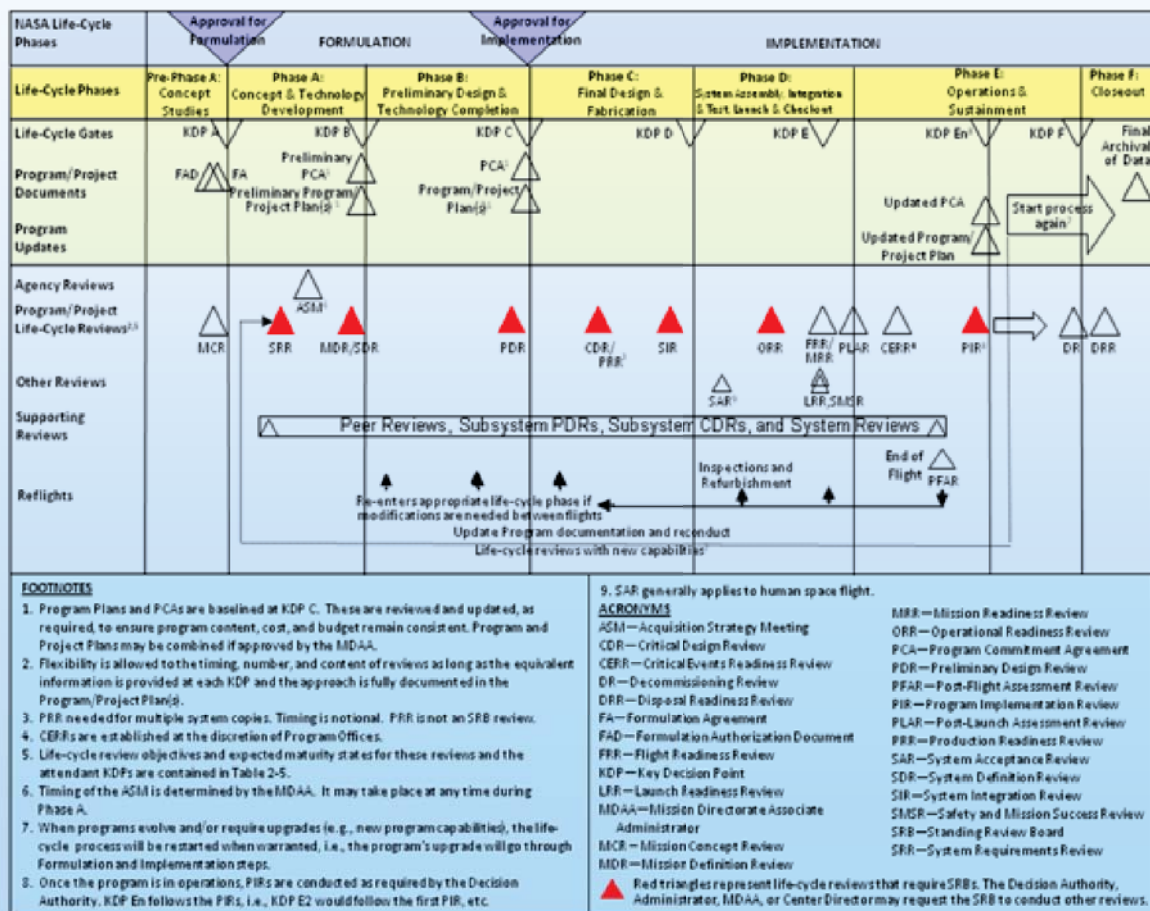
Outline

- **Abstract**
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- **Revisiting the RHA Steps**
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Abstract

- Radiation Hardness Assurance (RHA) is the process of ensuring space system performance in the presence of a space radiation environment.
- Herein, we present an updated NASA methodology for RHA focusing on content, deliverables and timeframes.



NASA Single-Project Program Life Cycle

NASA Procedural Requirement (NPR) 7120.5e, NASA Space Flight Program and Project Management Requirements w/Changes 1-10
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History

- In 1998, LaBel *et al.* presented at the Nuclear and Space Radiation Effects Conference (NSREC), a paper entitled:
 - “Emerging Radiation Hardness Assurance (RHA) issues: A NASA approach for space flight programs” [1].
- In that paper, a multi-step approach was proposed:
 - Define the hazard,
 - Evaluate the hazard,
 - Define requirements,
 - Evaluate device usage,
 - “Engineer” with designers, and,
 - Iterate process as necessary.
- This is the essence of the considerations for an RHA plan.

[1] K.A. LaBel, A.H. Johnston, J.L. Barth, R.A. Reed, C.E. Barnes, “Emerging Radiation Hardness Assurance (RHA) issues: A NASA approach for space flight programs,” *IEEE Trans. Nucl. Sci.*, pp. 2727-2736, Dec. 1998.



Objectives/Limitations of this Talk

- **Revisit the 1998 approach and update the general philosophy:**
 - Provide more codified details focusing on general deliverables and occurrence timeframes.
- **Limitations**
 - The 1998 paper provided general RHA process guidance, while this paper limits itself to RHA plan development and responsibilities.
 - We note that this method is focused on electrical, electronic, and electromechanical (EEE) parts and their performance in space. Material radiation assurance is deemed out of scope for this discussion



RHA and Responsibilities

- **RHA includes areas such as ionizing radiation environment modeling, spacecraft shielding analysis, as well as application analysis, radiation effects testing, and radiation performance evaluation of EEE parts.**
 - **EEE parts are deemed to include integrated circuits, discrete devices, as well as optical devices and systems.**
- **All spaceflight projects/payloads are required to develop an appropriate RHA plan.**
- **RHA is deemed to be the responsibility of the cognizant lead radiation engineer assigned to the project/payload.**
 - **Subject matter experts (SMEs), such as an environment specialist or technologist or test engineer, may provide additional support.**



Define the Hazard

- **Space radiation environment exposure (external to the spacecraft):**
 - **Deliverable: Mission Space Radiation Environment Exposure – to be completed during Mission Phase A (concept and technology development).**
 - **Included information (protons, electrons, galactic cosmic rays (GCRs), solar particle events):**
 - **Lifetime exposures (e.g., mission fluence),**
 - **Nominal exposures (e.g., average flux or fluence), and**
 - **Worst case event exposures or appropriate statistical models (e.g., solar event, worst case pass through South Atlantic Anomaly (SAA)).**
 - **Use of industry or NASA standard models as appropriate for the mission profile.**
 - **Study must be developed for specific mission orbital parameters and timeline.**
 - **If the spacecraft/payload contains a radioactive source, such as those used for power/propulsion, additional analysis for the induced environment shall be performed.**



Evaluate the Hazard

- **Transport of space radiation environment (internal to the spacecraft):**
 - Initially performed at a high level (i.e., simple dose-depth analysis), but may require a more detailed analysis of spacecraft geometry.
 - **Deliverable: Mission Space Radiation Analysis** – to be completed no later than Mission Phase B (preliminary design) with top level analysis (e.g., dose-depth curve) during Phase A. Consideration for earlier completion is advised.
 - Use of industry standard modeling tools such as NOVICE [2].
- **Iterative analyses may be performed based on updated spacecraft designs or if additional information is received.**
 - Updates may also occur in later Mission Phases based on design changes (final design, integration and test, and operations).

[2] *Experimental and Mathematical Physics Consultants, "NOVICE",*
<http://www.empc.com/novice.php>



Define Requirements

- **Requirements definition and specifications**
 - **Deliverable: Mission Space Radiation Requirements and Specifications** – to be completed during Mission Phase A (concept and technology development, but may be updated during later phases).
 - This may include a mix of top-down requirements such as system availability as well as EEE parts specific requirement levels such as a radiation tolerance minimum requirement.
 - An example reference of a single event effects (SEE) specification may be viewed at “Single Event Effects (SEEs) Specification Approach” [3].
 - We note that radiation requirements and specification are often integrated into larger function documents such as systems requirements.

[3] Kenneth A. LaBel, “Single Event Effects (SEEs) Specification Approach,” <http://radhome.gsfc.nasa.gov/radhome/papers/SEEsSpec.pdf>, Sept. 2013.



Evaluate Device Usage and “Engineer” with Designers

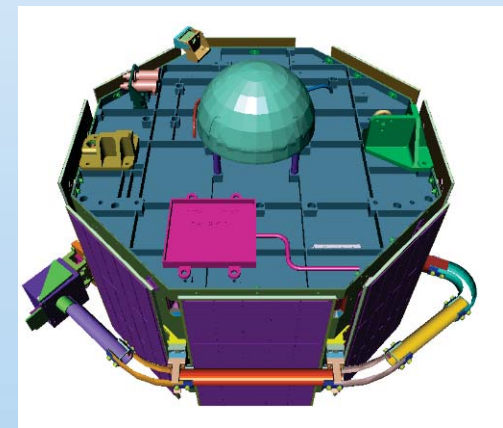
- **EEE parts list and electrical design review – to be performed during Mission Phases B-C (preliminary – final design).**
 - **Completion by Mission Critical Design Review (CDR):**
 - Some missions may require earlier deadlines depending on risk tolerance and completion of as-designed parts lists.
 - **This includes reviewing areas such as:**
 - Radiation tolerance/susceptibility including SEE rate predictions,
 - Mitigation approaches ,
 - Risk identification and application analysis,
 - This may include a single event effects criticality analysis (SEECA). [4]
 - Test requirements, test recommendations, test performance, and risk recommendations, and,
 - Design recommendations (when applicable).
- **Deliverable: Database of EEE components with radiation test data, analysis, and mitigation information. Test recommendations (and results/reports) are included.**

[4] Kenneth A. LaBel, "SEECA Single Event Effect Criticality Analysis," <http://nepp.nasa.gov/DocUploads/6D728AF0-2817-4530-97555B6DCB26D083/seecai.pdf>, Feb. 1996. Note that the Mr. LaBel is acting point of contact: original work was led by Dr. Michele Gates.



Iterate Process as Necessary

- Iteration of above analyses as designs/component selections change.
- This may occur for various reasons:
 - Movement of boxes/systems on a spacecraft
 - Failure of a EEE part during testing (radiation or otherwise)
 - Procurement delays (i.e., EEE part coming in too late)
 - Requirements “creep” – new or improved functionality now desired,
 - Descope or requirements change, and so on.



*NASA ST-5 Spacecraft: 3D Ray Trace
courtesy NASA*

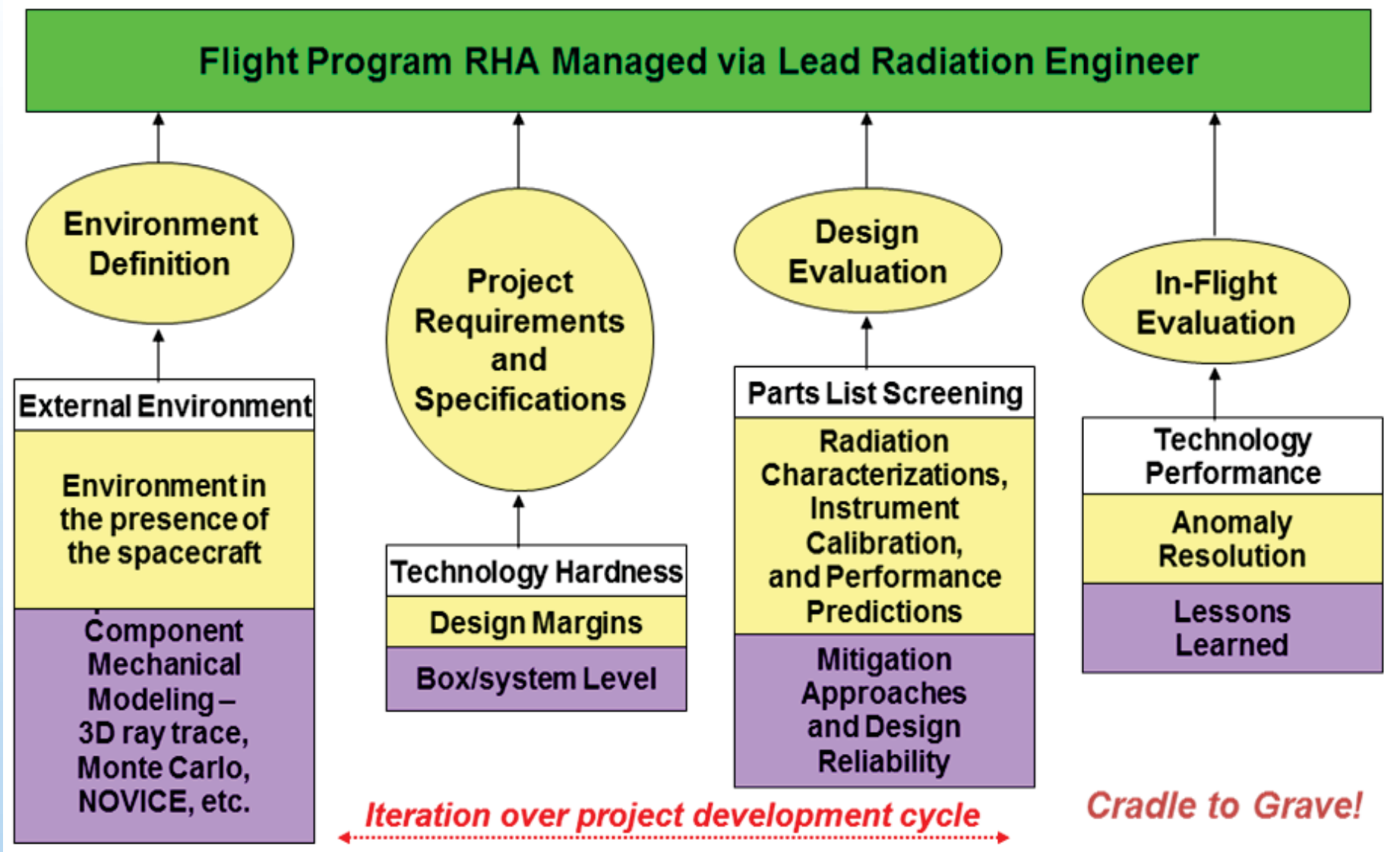


New Step: Evaluation of System Performance Post-launch

- While not “new,” this was not in the original 1998 paper for tracking system performance in-flight.
- Useful for:
 - Validating system performance such as error rates,
 - Developing lessons learned that can be utilized by other missions, and,
 - Preparation for anomaly resolution.
 - In an ideal world, sufficient housekeeping (thermal, power, etc...) and environment/position/time-tagging information is planned to aid any in resolving any anomalies that occur.
 - A key is to ensure that the documentation of EEE parts and system radiation performance expectations in-flight is documented (i.e., ability to recover test data easily, system validation test reports, etc...).



The Overall RHA Process





Diatribes 1: Validation of Mitigation

- Mitigation of radiation effects for EEE parts occurs at various levels ranging from:
 - Hardening a transistor design to
 - Adding voting logic to
 - Modifying system operations.
- What is not well codified is what entails sufficient (and statistically significant) validation of the mitigation option(s) used.
 - Consider system/board level fault-tolerance “validation” schemes such as:
 - Fault injection – May not adequately simulate the radiation effect, or,
 - Circuit modeling – There’s an old saying that “no one believes the model, but the modeler”.
 - These techniques may be adequate, but...
- Bottom line: **detailed consideration of adequacy of validation must be considered.**



Diatribes 2: Use of Standards and Guidelines

- **Using standards and guidelines is desired whenever possible.**
 - **This includes radiation testing (e.g., MIL-STD-883 Method 1019), environment models, predictive tools, and so forth.**
 - **It is important to note that new technologies often are “beyond” the guidance that currently exists in standards and guidelines and alternate considerations for test/analysis should be undertaken.**
 - **A relevant example would be SEE test requirements as presented by LaBel at HEART in 2008 [5].**

[5] Kenneth A. LaBel, "Are Current SEE Test Procedures Adequate for Modern Devices and Electronics Technologies?" http://radhome.gsfc.nasa.gov/radhome/papers/HEART08_LaBel_pres.pdf, Apr. 2008.



NASA: New Directions

- NASA has a wide variety of mission types
 - National assets to inexpensive CubeSats
- As such, mission criticality/requirements definition varies for EEE parts utilization
 - Higher reliability (Level 1 and 2) [6] to commercial off the shelf (COTS) used terrestrially.
- The following terms apply to the next chart
 - “Optional” – implies that you might get away without this, but there’s risk involved
 - “Suggested” – implies that it is good idea to do this
 - “Recommended” – implies that this *really* should be done
 - Where just the item is listed (like “full upscreening for COTS”) – this should be done to meet the criticality and environment/lifetime concerns

[6] NASA Parts Policy, NPD 8730.2C, <http://nodis3.gsfc.nasa.gov/displayDir.cfm?t=NPD&c=8730&s=2C>, Nov. 2008.



Notional Risk Starting Point

		Environment/Lifetime		
Criticality		Low	Medium	High
	Low	COTS upscreening/ testing optional; do no harm (to others)	COTS upscreening/ testing recommended; fault-tolerance suggested; do no harm (to others)	Rad hard suggested. COTS upscreening/ testing recommended; fault tolerance recommended
	Medium	COTS upscreening/ testing recommended; fault- tolerance suggested	COTS upscreening/ testing recommended; fault-tolerance recommended	Level 1 or 2, rad hard suggested. Full upscreening for COTS. Fault tolerant designs for COTS.
	High	Level 1 or 2 suggested. COTS upscreening/ testing recommended. Fault tolerant designs for COTS.	Level 1 or 2, rad hard suggested. Full upscreening for COTS. Fault tolerant designs for COTS.	Level 1 or 2, rad hard recommended. Full upscreening for COTS. Fault tolerant designs for COTS.



Summary

- In this presentation, we have provided an update on the NASA approach to RHA for EEE parts.
- We have attempted to provide a semblance of deliverables expected and when within the space system mission phase they should be considered.
- New discussions focused on
 - Ensuring proper validation of system radiation tolerance, and,
 - A caveat on only utilizing “standards/guidelines” for RHA performance.
- Lastly, a brief discussion of NASA’s emergent philosophy regarding EEE parts usage.



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